Progress Report

Characterization of Water Vapor Measurements at the DOE ARM Central Facility by Comparison with LASE Measurements During WVIOP3

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Scientific Goals

Accurate upper tropospheric water vapor measurements are crucial for computing shortwave and longwave radiation fluxes, radiative cooling rates, and understanding and modeling the formation and evolution of cirrus clouds. In order to characterize the upper tropospheric water vapor measurements and to resolve the remaining differences in measuring absolute water vapor amounts, ARM will conduct WVIOP3 during November and December 2000. Our primary goal is to use the Lidar Atmospheric Sensing Experiment (LASE) airborne Differential Absorption Lidar (DIAL) instrument to acquire measurements of water vapor during WVIOP3 to help characterize the upper tropospheric, absolute water vapor measurements acquired at the ARM Central Facility (CF). We will use the LASE measurements to characterize in detail the upper troposphere water vapor measurements acquired at the site. In particular, the LASE profiles will be used to characterize the SGP Raman lidar measurements in the upper troposphere and will be used to help examine how SGP Raman lidar water vapor performance varies between night and day. We will also examine the upper tropospheric water vapor measurements acquired by the ARM SGP Vaisala radiosondes, as well as new chilled mirror radiosondes that we anticipate will be launched during WVIOP3 by personnel from NASA/GSFC/Wallops Flight Facility. We will include the in situ measurements acquired aboard the DC-8 in our characterization of upper troposphere water vapor measurements. These include measurements from the diode laser and chilled mirror/cryogenic hygrometers. We will also use the LASE water vapor and cloud data acquired during WVIOP3 and in previous field missions to map out the relative humidity fields in the cirrus cloud environment to assess the supersaturation effects associated with the development of cirrus.

Special Accomplishments

- We have used LASE data acquired during the Pacific Exploratory Mission (PEM) Tropics B mission to map out the relative humidity fields over the tropical Pacific Ocean. We have used these LASE data, along with water vapor measurements acquired by in situ sensors on the NASA DC-8, to show that ice supersaturation conditions existed during about 5% of the time.
- We have used the LASE profiles of water vapor acquired during the PEM Tropics B mission to assess the water vapor analyses of the European Center for Medium Range Weather Forecasting (ECMWF) over the tropical Pacific Ocean. Comparisons of mean water vapor profile measurements between 0.5 and 14 km show excellent agreement between the ECMWF water vapor analyses and the LASE measurements. However, the ECMWF water vapor analyses do not show the supersaturation conditions measured by LASE and the in situ sensors.

Progress and Accomplishments

In preparation for the upcoming ARM FIRE Water Vapor Experiment (AFWEX) to be held during November and December 2000, we have devised a tentative flight plan. **Figure 1** shows this flight plan and **Figure 2** discusses the relevant details of this plan. We presented this plan at the Water Vapor IOP/AFWEX planning meeting that occurred during ARM Science Team Meeting in March 2000 and the other AFWEX participants endorsed this plan. We have also begun preparations for LASE deployment on the DC-8 for AFWEX. These preparations include ordering and installing upgraded optics for the Ti:sapphire laser of LASE.

We have used LASE water vapor and MTP temperature profiles acquired from the NASA DC-8 aircraft during the recent Pacific Exploratory Mission (PEM) Tropics B field mission over the tropical Pacific Ocean to investigate the relative humidity conditions associated with the topical cirrus cloud environment. During PEM Tropics B, LASE measured a total of about 104 hours of water vapor, aerosol, and cloud profiles over 18 science flights between March 6 and April 18, 1999. The Microwave Temperature Profiler (MTP) measured temperature profiles on 13 of these flights, so that about 73 hours of relative humidity profiles were computed using LASE water vapor and MTP temperature data. These flights generally occurred over the tropical Pacific Ocean between 10^{o}N and 30^{o}S and 170^{o}E and 90^{o}W. LASE does not measure water vapor profiles within about 1 km above and below the aircraft, and to cover this region, in situ water vapor measurements collected by cryogenic and laser diode hygrometers on the DC-8 are used to interpolate between the LASE nadir and zenith water vapor profiles. **Figure 3** shows examples of relative humidity (ice) (RHI) and cloud profiles derived from LASE and MTP data acquired between 02:00 to 05:00 UT on April 14, 1999, during the transit flight from Tahiti to Easter Island. Cirrus clouds were observed both above and below the aircraft during the flight as shown by the LASE total scattering ratio profiles. The aircraft also flew through cirrus clouds between 04:20-04:40 UT during this flight. The cryogenic and laser diode in situ sensors on the DC-8 indicated ice supersaturation conditions occurred during these in-cloud periods. The relative humidity profiles derived from LASE and MTP measurements showed ice supersaturation occurred predominantly above the aircraft. The temperature at flight level (~10.2 km) was about –35^{o}C. **Figure 3** also shows a comparison of the relative humidity profiles derived from the ECMWF model along this same flight path. The model generally represents the large-scale humidity variations along the path, but misses the small scale, high relative humidity conditions near the cirrus clouds.

Frequency distributions of relative humidity and temperature constructed using the RHI and temperature profiles derived from the LASE and MTP measurements acquired during the PEM Tropics B deployment are shown in **Figure 4a**. These distributions were constructed using 1^{o}C and 1% RH bin sizes. These distributions show that ice supersaturation conditions occurred about 5% of the time during PEM Tropics B and are consistent within the range of between 5%-20% derived using in situ sensors on commercial and research aircraft. Similar distributions computed using DC-8 in situ data show similar results. The somewhat low frequency of ice supersaturation derived from the LASE and MTP data during PEM Tropics B may be due to two reasons. First, the LASE water vapor retrievals were generally limited to altitudes below 14 km and, therefore, did not sample the region near the tropical tropopause where thin cirrus and high relative humidity have been often observed. Second, the PEM Tropics B flight tracks were often designed to avoid clouds to optimize lidar profiling of ozone and water vapor. We are beginning similar studies using LASE and MTP data acquired during the SAGE-III Ozone Loss and

Validation Experiment (SOLVE) that took place over the Arctic region between December 1999 and March 2000.

We have also compared ECMWF water vapor and relative humidity analyses with the LASE water vapor measurements acquired during PEM Tropics B. **Figure 4b** shows a comparison of the mean relative humidity (ice) profiles derived from all LASE data acquired during flights 10 through 22 and the corresponding profiles derived from ECMWF data. The mean profiles show excellent agreement. However, **Figure 4a** shows that the distribution of relative humidity, especially above RHI>100%, does not match that measured by LASE during PEM Tropics B. The ECMWF analyses currently do not permit ice supersaturation conditions.

Extended Abstracts

"Lidar Measurements of Relative Humidity and Ice Supersaturation in the Upper Troposphere", Richard A. Ferrare, Edward V. Browell, Syed Ismail, Vincent G. Brackett, Marian B. Clayton, Marta Fenn, Lorraine Heilman, Susan A. Kooi, David D. Turner, Michael J. Mahoney, Reginald E. Newell, Yong Zhu, Eric Jensen, John Barrick, Glen Sachse, 20th International Laser Radar Conference, July 10-14, 2000, Vichy, France.

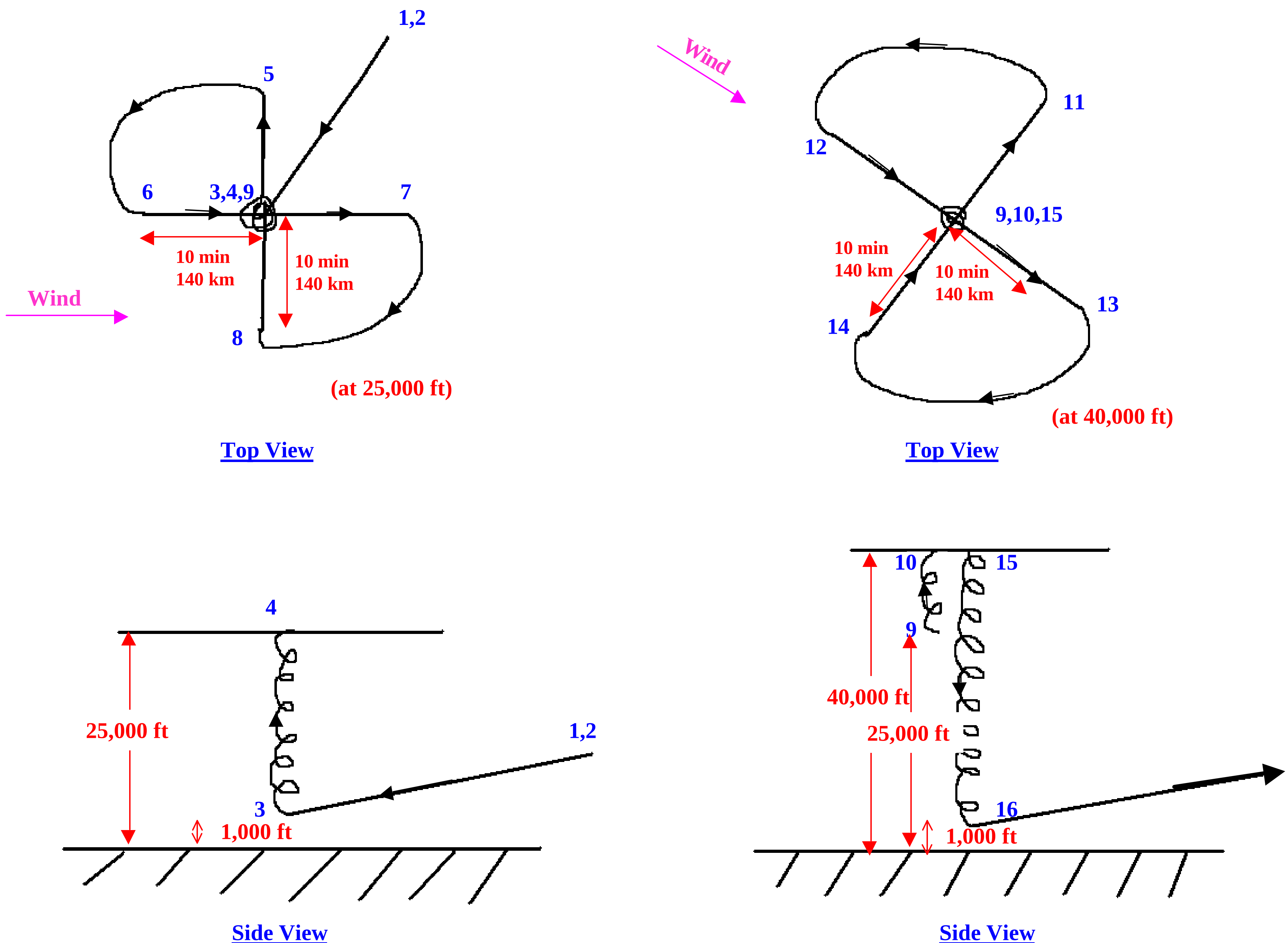

Figure 1. Tentative DC-8 plan for AFWEX.

DC-8 Issues for AFWEX

1. Must plan to avoid radiosondes released from CART site. Should try to plan for DC-8 to be below radiosonde. Therefore, could try to launch sonde while aircraft is at low altitude on the way to or from site. Alternatively, if DC-8 is in vicinity and at high level, then must launch sonde when DC-8 is upwind of site. Note that radiosonde rise rate is about 1000 feet/minute which is about the same rate of ascent or descent desired for DC-8 spirals.
2. DC-8 ascent and descent rate should be <= 1000 ft/minute to give good resolution and response for cryogenic hygrometer. Descents are better than ascents for cryogenic hygrometer since sensor moving to larger water vapor amounts and reduce chance of overshoot.
3. To satisfy eye safety considerations, bank angle must be <= 10 degrees for LASE to transmit during spiral ascents and descents. The radius of the spiral ascents and descents would vary from about 5 km when the DC-8 is at low altitude to 20 km when the aircraft is at high altitude.
4. DC-8 normal flight speed is about 450 knots (14 km/min)
5. MWR tip curve direction may be substituted for wind direction

Draft flight plan

	Time (min)	Total (min)	Point
1. Takeoff from McConnell AFB and climb to 12-18 kft.	0	0	1
2. Descent to 1000 ft en route to CART site (launch sonde?)	20	20	2
3. Spiral ascent from 1000 ft to 25000 ft at 1000 ft/min	25	45	3
4. Out of spiral, leg 1A perpendicular to wind direction	10	55	4
5. Line up for legs 2A and 2B along wind direction	10	1 hr, 5min	5
6. Lines 2A and 2B along wind direction	20	1 hr, 25 min	6
7. Line up for leg 1B	10	1 hr, 35 min	7
8. Line 1B perpendicular to wind direction	10	1 hr, 45 min	8
9. Spiral ascent over CART Site from 25000 to 40000 ft	15	2 hr	9
10. Out of spiral, begin leg 3A perpendicular to wind direction	10	2 hr, 10 min	10
11. Line up for legs 4A and 4B along wind direction	10	2 hr, 20 min	11
12. Lines 4A and 4B along wind direction	20	2 hr, 40 min	12
13. Line up for leg 3B	10	2 hr, 50 min	13
14. Line 3B perpendicular to wind direction	10	3 hr	14
15. Spiral descent over CART Site from 41000 ft to 1000 ft at 1000 ft/min	40	3 hr, 40 min	15
16. Return to McConnell AFB (launch sonde?)	20	4 hr	16

Figure 2. Description of tentative DC-8 flight plan for AFWEX.

PEM Tropics B Flight 19 Tahiti to Easter April 15, 1999

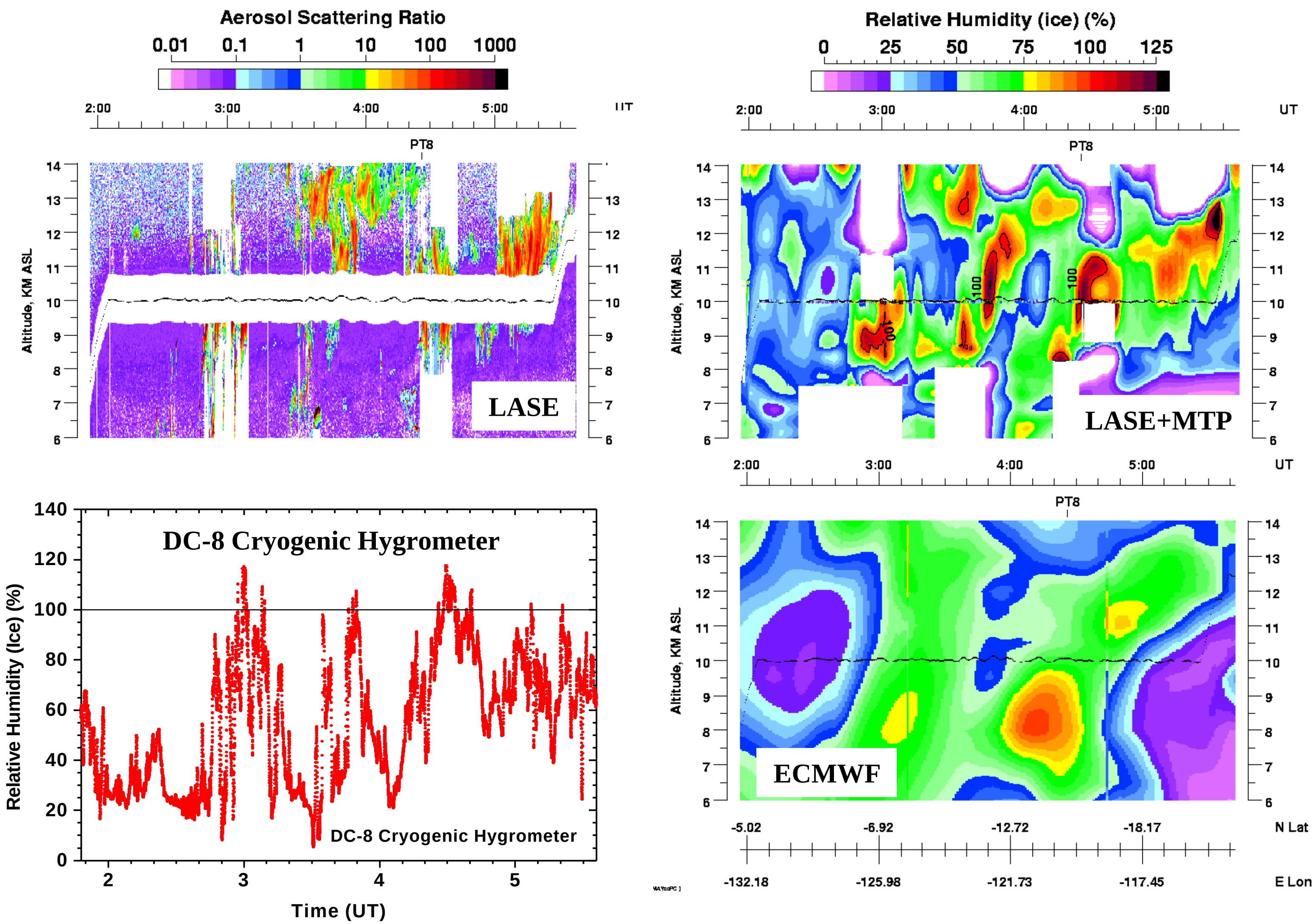

Figure 3. (top left) LASE aerosol scattering ratio profiles showing location of cirrus clouds during PEM Tropics B flight 19. The DC-8 flight altitude is indicated by the black line in the image. (top right) relative humidity (ice) derived from LASE water vapor and MTP temperature measurements acquired during this flight. (bottom left) relative humidity (ice) measured by DC-8 in situ cryogenic hygrometer on this flight. (bottom right) relative humidity (ice) derived from ECMWF analyses during this flight.

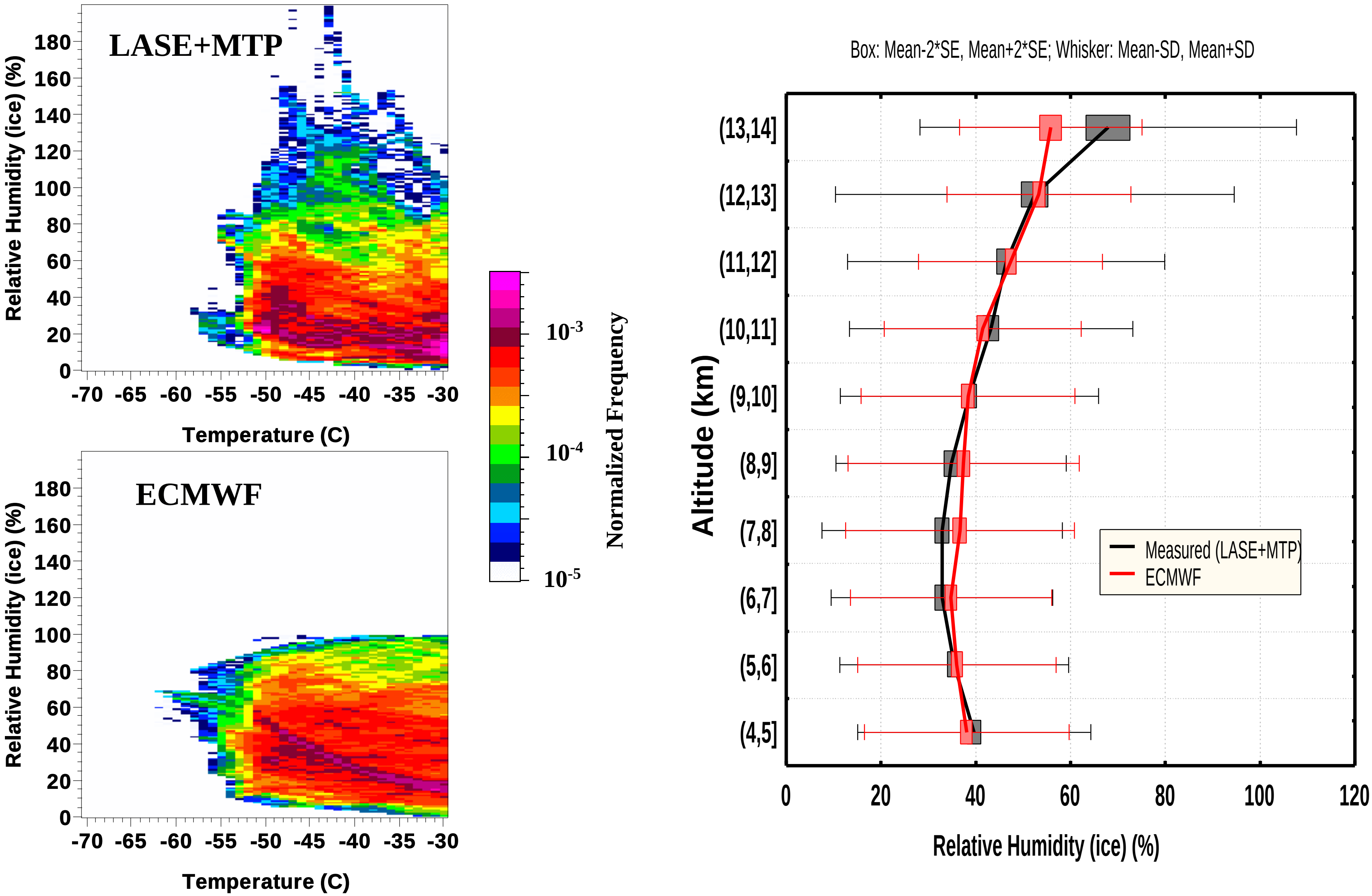

Figure 4. a) (left) Distribution of relative humidity (ice) derived from LASE water vapor and MTP temperature profiles (top) and from ECMWF analyses (bottom) between 4-12 km for PEM Tropics B flights 10-22. **b)** (right) mean relative humidity (ice) profiles derived from LASE and MTP measurements and ECMWF analyses for these same flights.